Wil Barnett
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Proposal

Abstract

Since becoming a College Student Investigator in NASA's Planetary Data System Program, my job has been to look at and analyze images taken during the Deep Impact mission. Before Deep Impact, astronomers had to rely mainly on theoretical models to explain and describe the interior structure and evolution of comets. However, the Deep Impact mission opened new doors and made it possible for astronomers to be able to study comets using in-situ scientific data. In my research, I will study the variations in the albedo of the Deep Impact ejecta as a function of time in order to learn more about the layering of material in the nucleus at the impact site. The first step taken will be to utilize the images taken by the Medium Resolution Instrument both before and after the impact in order to measure the change in the brightness due to the shadow cast by the cone of ejecta. The difference in brightness in the shadowed area from before and after impact can then be used to calculate the optical depth of the ejecta cloud. In addition, with the help of information provided by the SPICE dataset, a geometric model of the cone of ejecta will be created, so that after determining the difference in brightness and deriving the optical depth, I will be able to pinpoint which area of the cone corresponds to each pixel in the shadowed area. Also, the geometric model of the cone will allow for a calculation of the absolute brightness of each area of the cone. With the knowledge of both the absolute brightness and the optical depth of the cone at each point, it becomes possible to calculate the corresponding albedos of the ejecta particles. This would then allow for a general understanding of where ices exist on the Tempel 1, in addition to where other dusts and grains may lie in the cometary nucleus. It would also allow me to make some conclusions as to the chemical and/or mineralogical make-up of the ejecta.

Introduction

The comet being studied, 9P/Tempel 1, was discovered and named after Wilhelm Tempel on April 3, 1867. One hundred thirty-eight years later, on July 4, 2005 at 5:52 UTC, a Deep Impact spacecraft struck the surface of the comet, forming a crater that is roughly estimated at being over 200 meters wide and nearly 50 meters deep,. This collision was no accident, however; it was the planned stage of a groundbreaking experiment. Before July 4 2005, photometry and spectroscopy had allowed astronomers to study the coma as comets approached perihelion in their orbits, but there were no scientific observations of the interior of a comet, meaning "the [exact] relation of the coma's composition to the solid composition of the nucleus is uncertain (A'Hearn, et al., 2005)." That all changed with the Deep Impact mission, which set out with the goal of being able to make scientific data on the nucleus of the comet 9P/Tempel 1 available in order to learn more about the interior structure and evolution of the comet. In addition, since no other spacecraft has ever touched the surface of a comet, knowledge of the interior of Tempel 1 can be used as a clue as to the composition of the other short period comets in our Solar System.

The main three goals of the Deep Impact mission were: 1) to gain information about the nucleus of 9P/Tempel 1, 2) to learn more about the composition of the sub-surface layers of the comet, and 3) to put the pieces back together and learn about the history and evolution of the nucleus. Using the data gained from this mission, astronomers can extrapolate their findings to other similar comets to understand how they formed as well. In addition, the composition of this and other comets can be used to help understand the evolution of our Solar System. Comets are different from other bodies in our solar system. Even though, as with other solar-system bodies, they were formed a long time ago via accretion from materials that were floating around in the

Solar System, their interiors never became molten. When planets were forming, they gradually accreted and got very large. After a while, their molten interiors differentiated, meaning that the higher density materials moved to the core, while the lighter density materials moved radially outward. Comets, however, did not form hot; they just accreted materials, with each layer simply building up on top of one another. Thus, if we can learn about the composition of the materials of Tempel 1, it can tell us about the composition of the Solar System as the planets were forming.

Almost immediately after the collision occurred, scientists began to analyze the images of the collision. The analysis showed that the comet's outer layer was made up of mostly micrometer-sized particles, and that these particles were in fact not strong at all (A'Hearn, et al., 2005). This had been one of the trepidations about sending a probe up to collide with the comet, for it was unsure how much of an impact the spacecraft would make due to the lack of knowledge regarding the particle strength. In addition, the local gravitational field and the average density of the nucleus were calculated. Thirdly, the spectroscopy was used in order to determine the composition of the nucleus and excavated materials. Spectroscopy showed that there was a "large increase in organic material [that] occurred during and after the event," with materials such as carbon dioxide created in abundance after the collision. It was also shown that there are "three anomalously colored areas on the surface of the comet that appeared to include water ice based on their near-infrared spectra, which include diagnostic water ice absorptions at 1.5 and 2.0 micrometers (J.M. Sunshine, et al., 2006)." Despite all of the groundbreaking discoveries made after the mission was completed, there is still much more than can be determined regarding Tempel 1.

Research Question

By using the properties of the shadow created by the cone of Deep Impact ejecta of the comet Tempel 1, can we make conclusions about the chemical/mineralogical make-up and physical properties of the cometary nucleus?

Method

In order to answer this question, I will be using the images from the NASA Planetary Data Systems Small Bodies Node that were collected by the instruments on board of the Deep Impact spacecraft. Most all of the computer analysis will be done using a Linux operating system with the help of the Interactive Data Language (IDL). The main set of Deep Impact images are from the Medium and High Resolution Instruments (MRI and HRI) that were on board the spacecraft, however I predominately am using the MRI images. This is because the HRI has a much lower imaging rate than its counterpart (2 img/sec compared to 15-20 img/sec for MRI), which is primarily due to the fact that a much larger sub-frame was used on the detector.

The first step in my research is to determine the optical depth of the cone of ejecta. This is done by first finding a set of "before" and "after" images that contain the area of the nucleus that is in the shadow of the cone. Then, by comparing the intensity (I) values of the shadowed region after the collision to the intensity (I_0) values of that same region of the nucleus before the collision, the optical depth can be calculated using the equation $I = I_0 e^{-\tau}$. To reduce the random errors and noise, I averaged together many before-the-collision images. Then, using a set of after-the-collision images, the optical depth of the cone of ejecta as function of time can be calculated.

Another important step must be made before it is possible to pinpoint which areas of the ejecta cone correspond to the shadowed area, and thus, the estimations of optical depth. Namely, a geometric model of the ejecta cone must be made. This will be done by using information given from the SPICE dataset, which contains geometric information (altitudes, azimuths, etc.) and coordinate systems mapping all of Tempel 1. If the altitude and azimuth of the Sun in each part of the shadow are known, then an imaginary ray can be drawn from that point on the nucleus towards the Sun. This ray should intersect the cone of ejecta on its way to the Sun, and in turn should show the areas of the cone that are creating that part of the shadow that the ray is drawn from. As a result, the numbers that are received from the analysis of the shadow's intensity values can be pinpointed to certain areas of the cone. This is still a work in progress, and will be for probably quite some time, but the creation of this 3-D model is an invaluable step to the calculations of the albedo and the following analysis of chemical/mineralogical make-up of the ejecta.

Finally, once the 3-D model of the cone is created, I will estimate the absolute brightness of the cone. This value, in conjunction with the corresponding optical depth, will allow for a calculation of the albedo of the particles in the ejecta cone. Really, the particle albedo is the ratio of the light scattered by the particle to the light scattered and absorbed (extinction of the light). Thus, knowing that the brightness of the ejecta cone will show how much light was scattered, and that the optical depth will show how much light was absorbed, an estimation for the albedo of the particles can be made. Then, once I know both the albedo and the optical depth of each part of the cone, I can make conclusions as to the composition of the individual grains in the cone, which in turn reveal the composition of the nucleus. For example, if the albedo of the ejecta particles is very close to unity, it is more likely that the ejecta are ices at that point. My project, being somewhat similar to Ashley King's research in nature, should see more ices present in the nucleus than her research revealed. This is because I will be looking at the **shadow on the surface** in order to analyze the images, whereas she looked at the **limb** of the comet. Thus, it is likely that many of the ices that were ejected immediately after impact had already sublimed by the time they reached the limb of Tempel 1, meaning she had less chances to see it in her data/images.

In summary, the goal of my research is ultimately to be able to use the optical depth and the albedo of the ejecta cone to make educated conclusions about the chemical/mineralogical make-up and the physical properties of the cometary nucleus. Having an intimate knowledge of the interior structure of comets is something that has escaped astronomers for some time, and I hope to be able to learn more about the topic with the resources given by the Planetary Data Systems Small Bodies Node archive.

Timeline

December 2008
- Continue to work with FITS files
- Rough Draft of proposal due on the 22nd

January 2009
- Practice Presentation with Drs. A'Hearn, Kolokolova, etc.
- Final draft of Proposal by the 19th
- Meeting/presentation of proposal at Goddard at 4:00pm on the 26th
- Begin brunt of work on creating a 3D model for cone of ejecta

February 2009
- Continue work on geometric model with Tony Farnham
- As well as continue the analysis of FITS files

March 2009
- Work on the presentation to be given to the PDS Management via teleconference
- Continue working on geometric model

April 2009
- Continue geometric model analysis
- Present proposal to PDS Management Council, via teleconference
- Begin and make a rough draft of my abstract and submit to A'Hearn

May 2009
- Finish work on creating the geometric model of the cone of ejecta
- Finish draft of Abstract and submit to Mentor for professional meeting

June 2009
- Calculations of the optical depth of the ejecta cone and albedo of its particles
- Begin work on my rough draft of my final report
- Send abstract to a professional meeting (A'Hearn's choice)

July 2009
- Finish rough draft of final report

August 2009
- Start final report

September 2009
- Finish final draft of report to present at Professional Meeting
- Work on presenting my paper with Drs. A'Hearn, Kolokolova, etc.

October 2009
- Present Paper at Professional Meeting in Puerto Rico

May 2010
- Final Summary Due to PDS CSI office by the 21st

Works Cited

A'Hearn, M. F., M. J. S. Belton, W. A. Delamere, J. Kissel, K. P. Klaasen, L. A. McFadden, et al.: 2005, *Science* **310**, 258.

Sunshine, J. M., M. F. A'Hearn, O. Groussin, et al.: 2 February 2006, *Science* **311.**